US010811450B2

(12) United States Patent
Kim et al.

(10) Patent No.: US 10,811,450 B2
(45) Date of Patent: Oct. 20, 2020

(54) **IMAGE SENSORS**

(71) Applicant: **Samsung Electronics Co., Ltd.**, Suwon-si, Gyeonggi-do (KR)

(72) Inventors: **Bomi Kim**, Yeongju-si (KR); **BumSuk Kim**, Hwaseong-si (KR); **Jung-Saeng Kim**, Seoul (KR); **Yun Ki Lee**, Hwaseong-si (KR); **Taesub Jung**, Hwaseong-si (KR)

(73) Assignee: **Samsung Electronics Co., Ltd.**, Suwon-si (KR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **16/123,092**

(22) Filed: **Sep. 6, 2018**

(65) **Prior Publication Data**

US 2019/0214421 A1 Jul. 11, 2019

(30) **Foreign Application Priority Data**

Jan. 9, 2018 (KR) 10-2018-0002920

(51) **Int. Cl.**
H01L 27/146 (2006.01)
H04N 5/341 (2011.01)

(52) **U.S. Cl.**
CPC ***H01L 27/14621*** (2013.01); ***H01L 27/1463*** (2013.01); ***H01L 27/1464*** (2013.01); ***H01L 27/14685*** (2013.01); ***H04N 5/341*** (2013.01); *H01L 27/14627* (2013.01)

(58) **Field of Classification Search**
CPC H01L 27/14621; H01L 27/14645
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,628,331	B1	9/2003	Bean
6,864,022	B2	3/2005	Machiguchi et al.
7,990,445	B2	8/2011	Rhodes et al.
8,259,201	B2	9/2012	Stuck et al.
9,673,236	B2	6/2017	Jin et al.
9,926,664	B2	3/2018	Kono et al.
2009/0086065	A1	4/2009	Kim et al.
2009/0115874	A1	5/2009	Kim et al.
2016/0056198	A1	2/2016	Lee et al.
2017/0104020	A1	4/2017	Lee et al.
2017/0154911	A1	6/2017	Jin et al.

FOREIGN PATENT DOCUMENTS

JP	5037044	B2	9/2012
JP	2017098533	A	6/2017

OTHER PUBLICATIONS

Singapore Search Report corresponding to Application No. 10201900129Q (dated Jul. 11, 2019; 2 pages).
Extended European Search Report corresponding to EP3509107 (dated Aug. 2, 2019) (9 pages).

Primary Examiner — Wael M Fahmy
Assistant Examiner — Sarah K Salerno
(74) *Attorney, Agent, or Firm* — Myers Bigel, P.A.

(57) **ABSTRACT**

Image sensors are provided. The image sensors may include a plurality of unit pixels and a color filter array on the plurality of unit pixels. The color filter array may include a color filter unit including four color filters that are arranged in a two-by-two array, and the color filter unit may include two yellow color filters, a cyan color filter, and one of a red color filter or a green color filter.

20 Claims, 14 Drawing Sheets

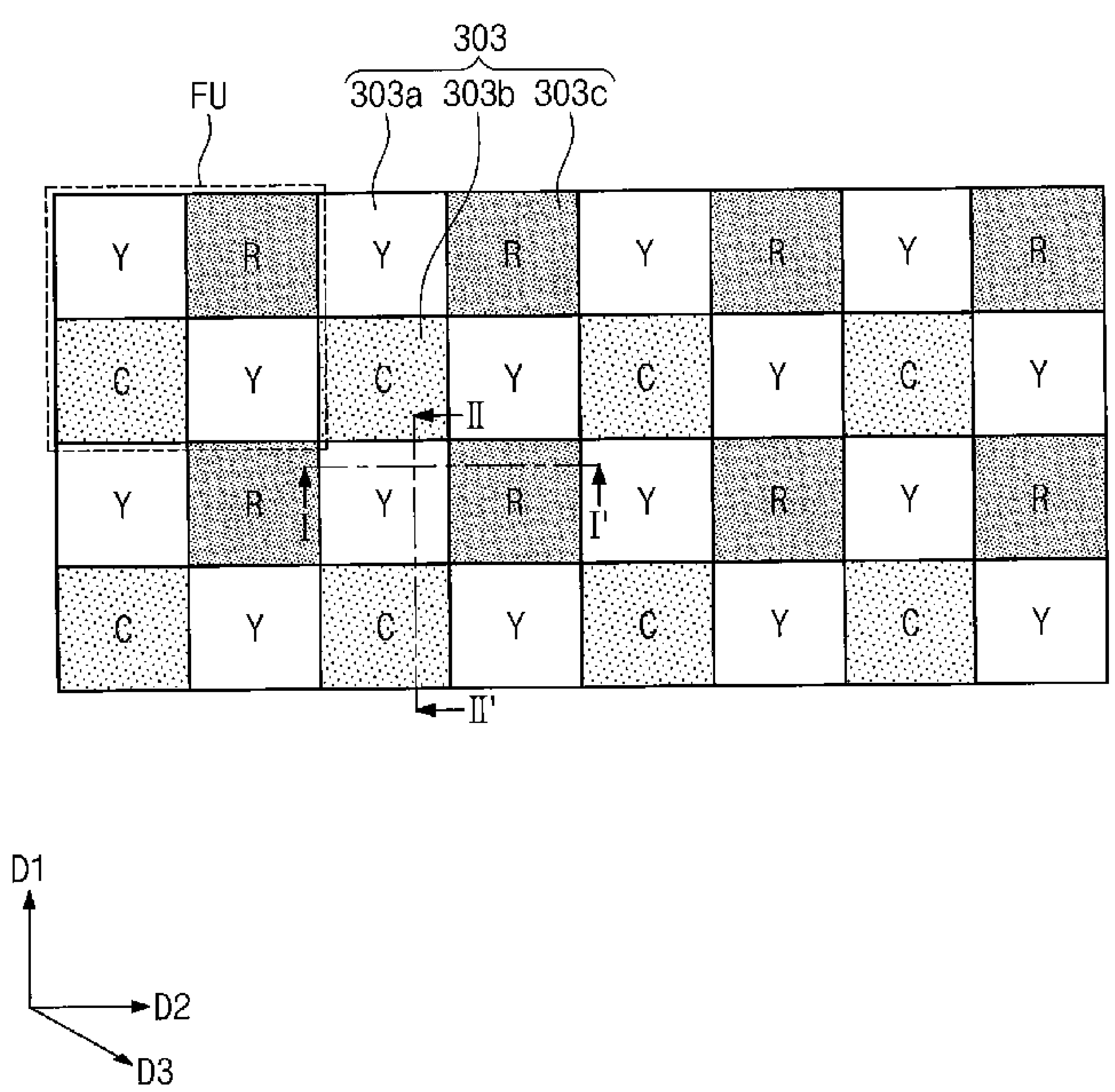


FIG. 1

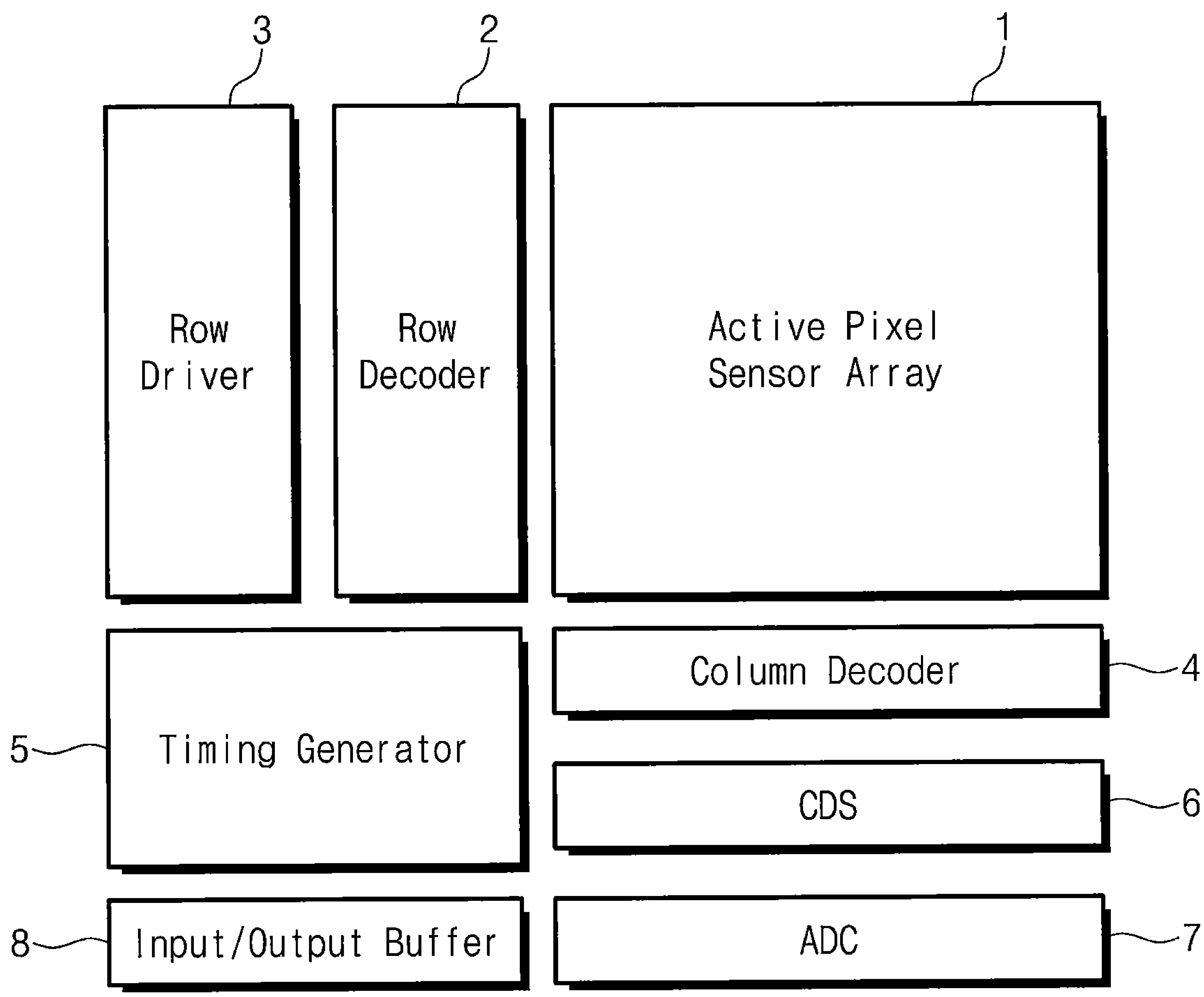

3
2
1
Row
Driver
Row
Decoder
Active Pixel
Sensor Array
Column Decoder
4
5
Timing Generator
CDS
6
8
Input/Output Buffer
ADC
7

FIG. 2

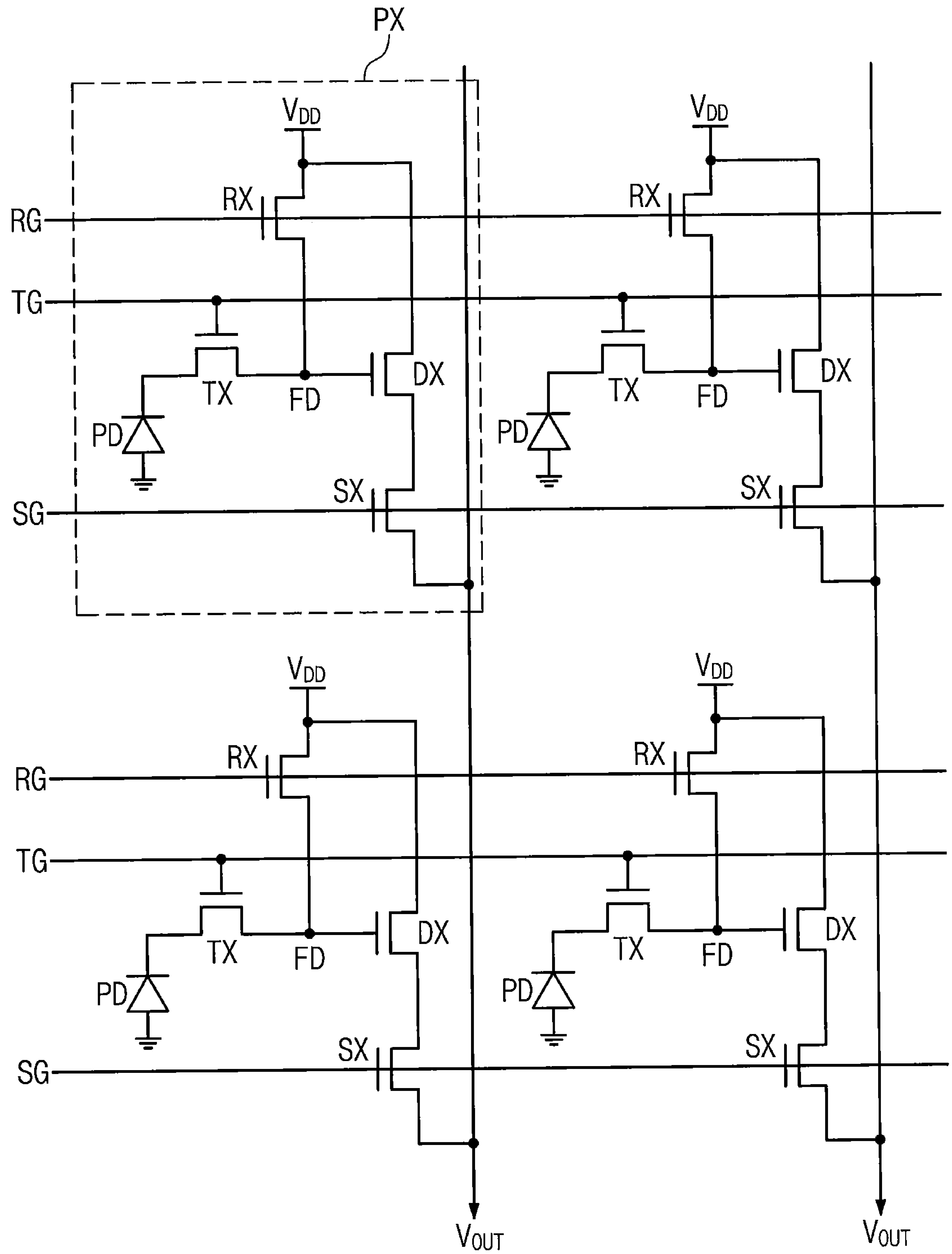


FIG. 3

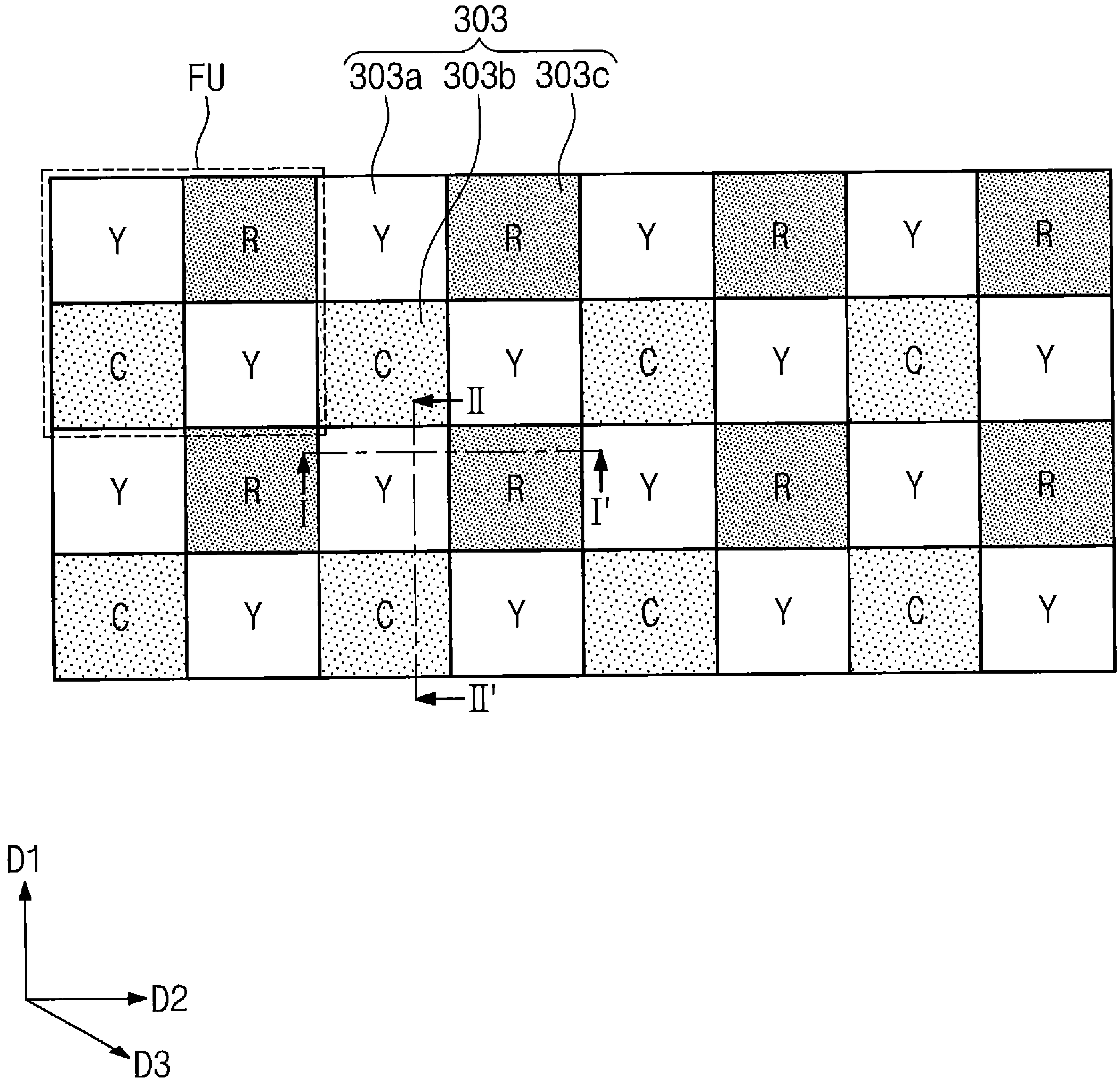

303
FU
303a
303b
303c
Y
R
Y
R
Y
R
Y
R
C
Y
C
Y
C
Y
C
Y
Y
R
Y
R
Y
R
Y
R
C
Y
C
Y
C
Y
C
Y
II
I
I'
II'
D1
D2
D3

FIG. 4A

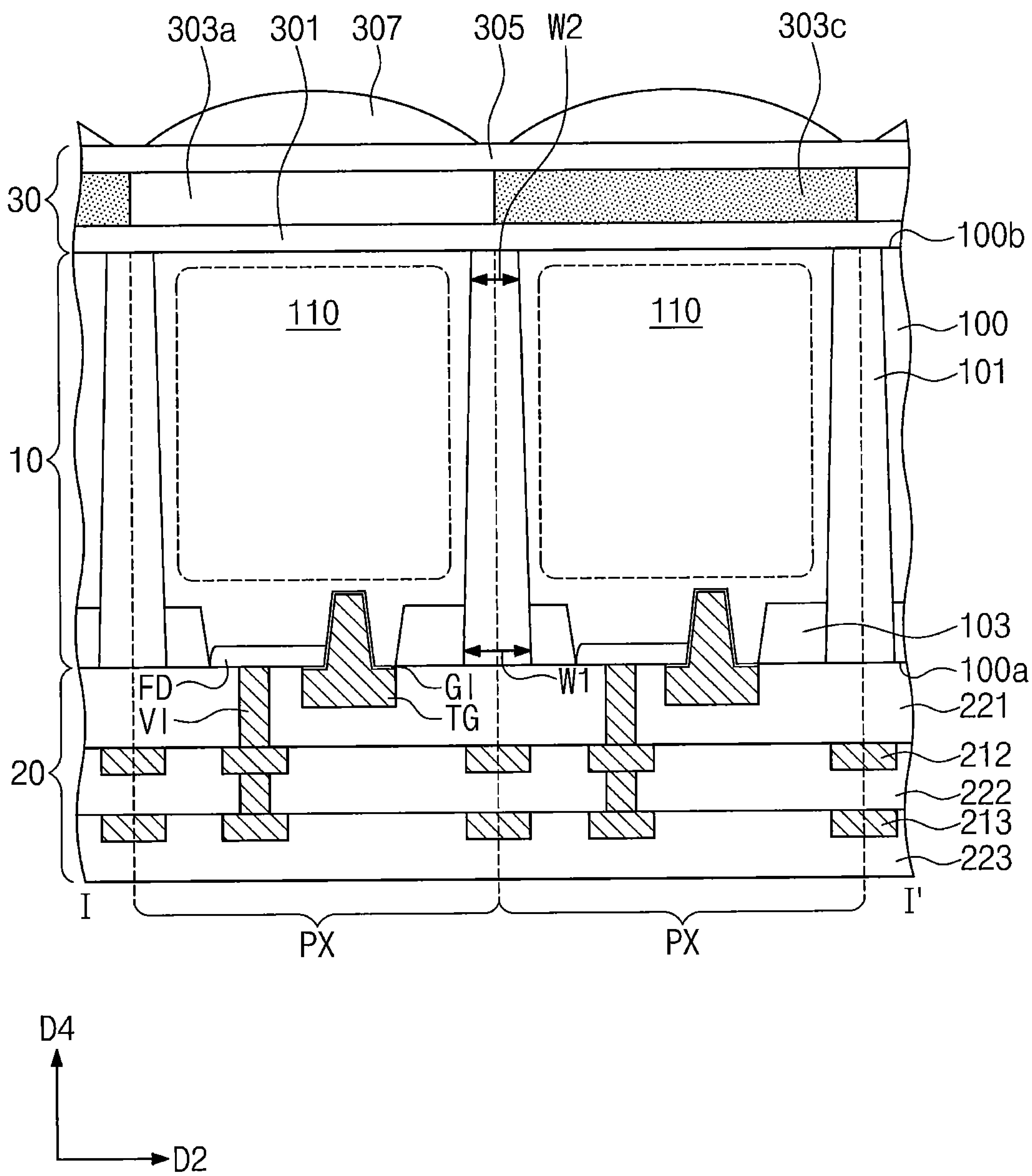
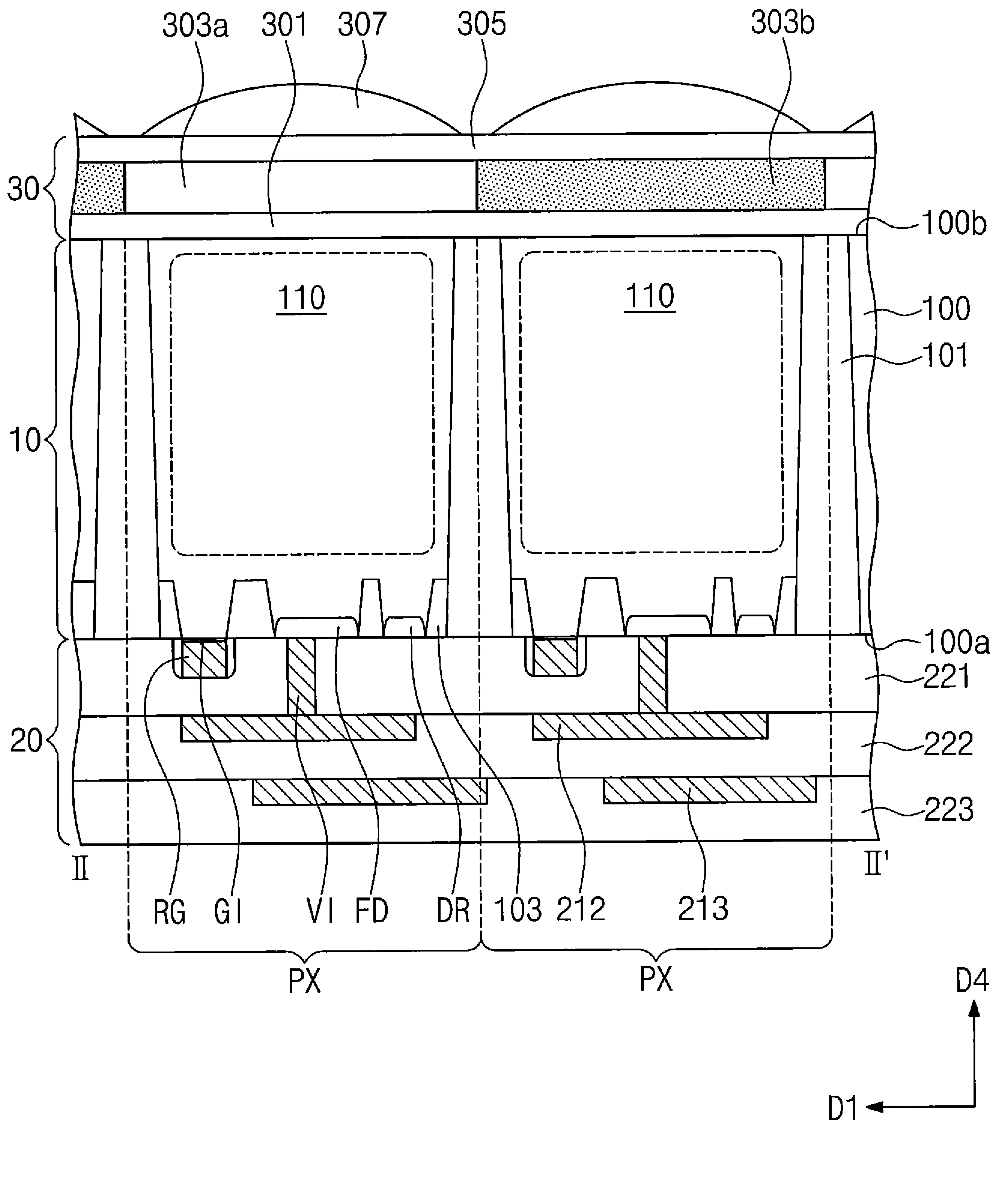

303a
301
307
305
W2
303c
30
100b
110
110
100
101
10
103
100a
FD
GI
W1
VI
TG
221
212
20
222
213
223
I
I'
PX
PX
D4
D2

FIG. 4B



303a
301
307
305
303b
30
100b
110
110
100
101
10
100a
221
20
222
223
II
II'
RG
GI
VI
FD
DR
103
212
213
PX
PX
D4
D1

FIG. 5A

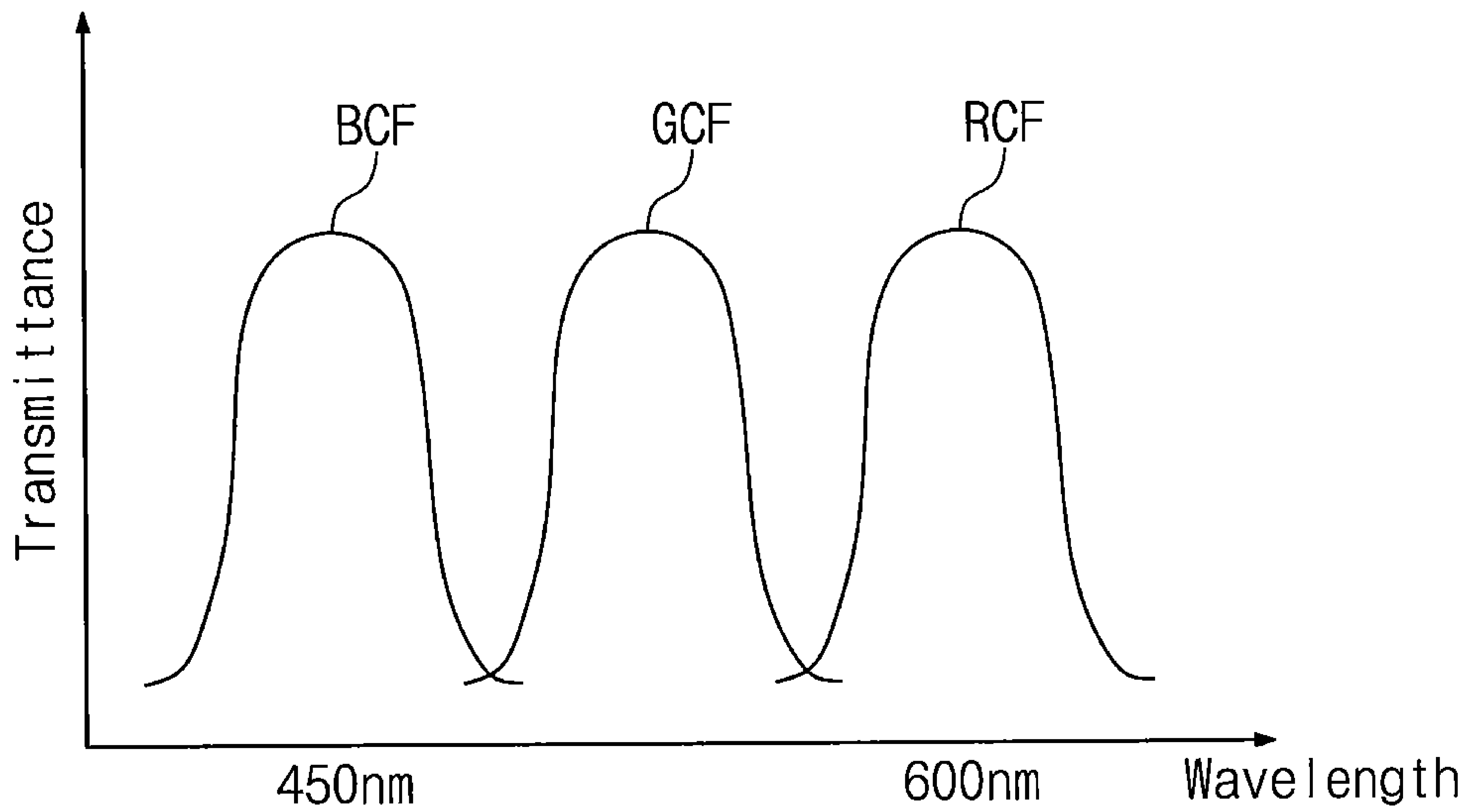

BCF
GCF
RCF
Transmittance
450nm
600nm
Wavelength

FIG. 5B

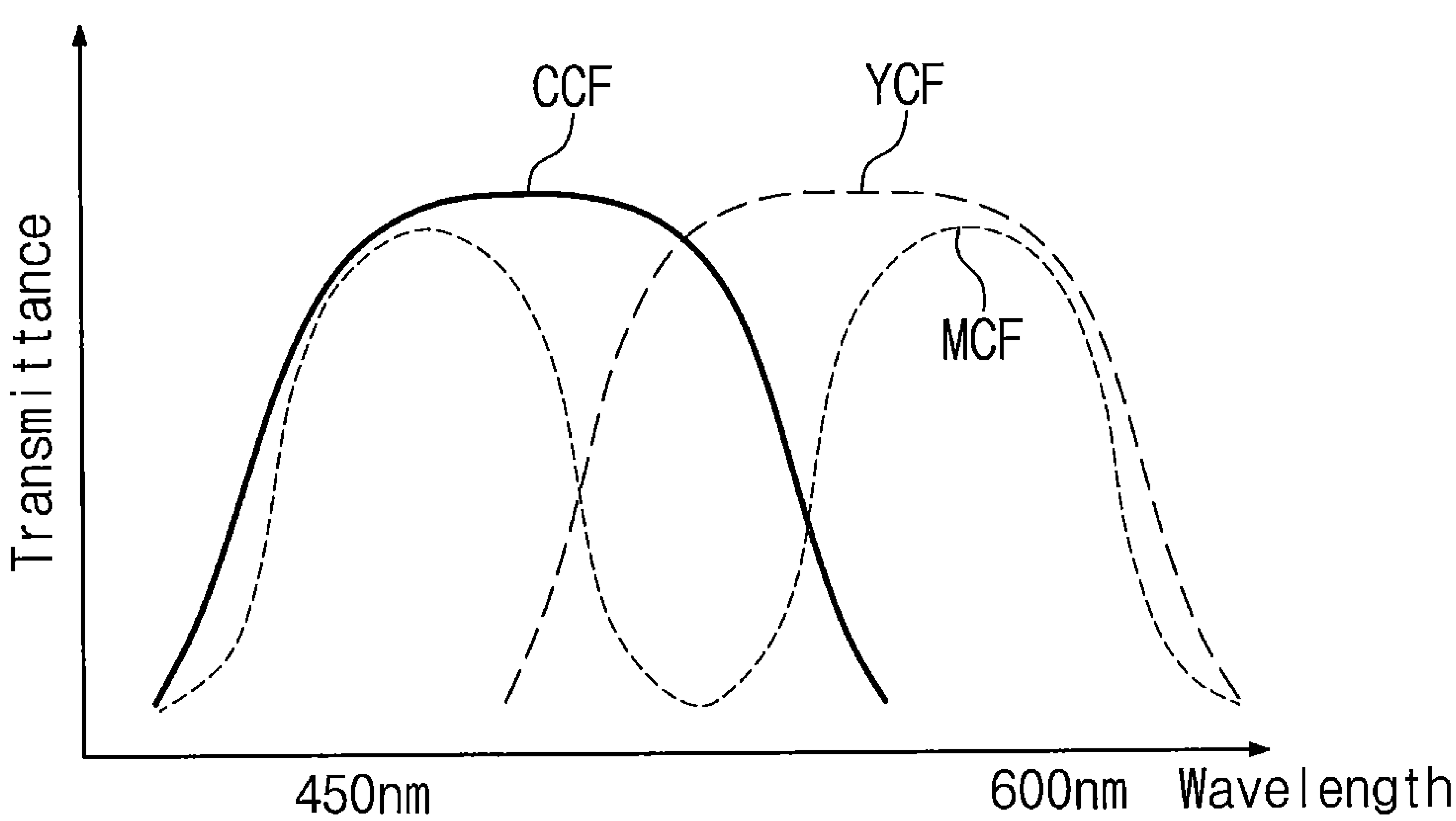

CCF
YCF
MCF
Transmittance
450nm
600nm
Wavelength

FIG. 6

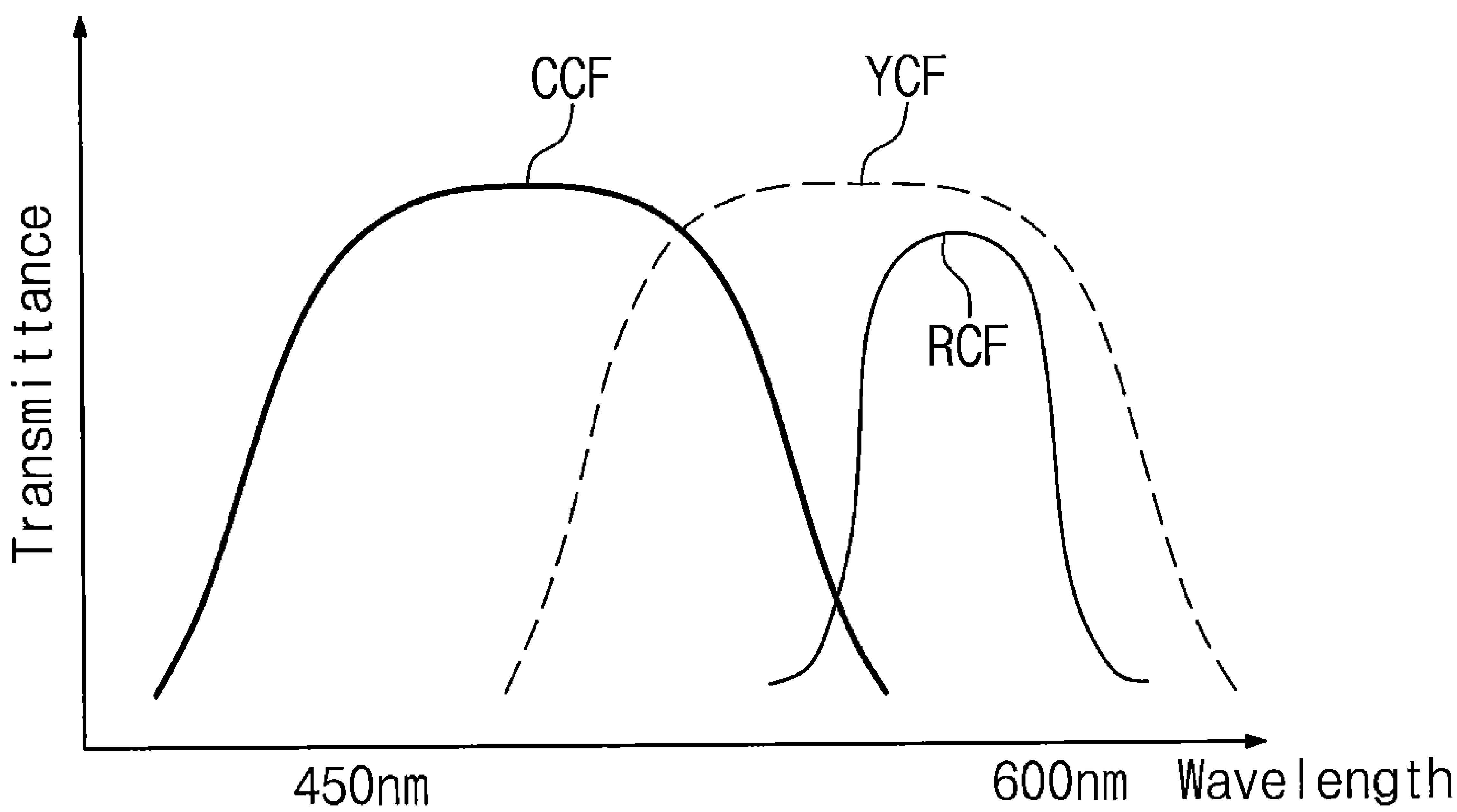


FIG. 7

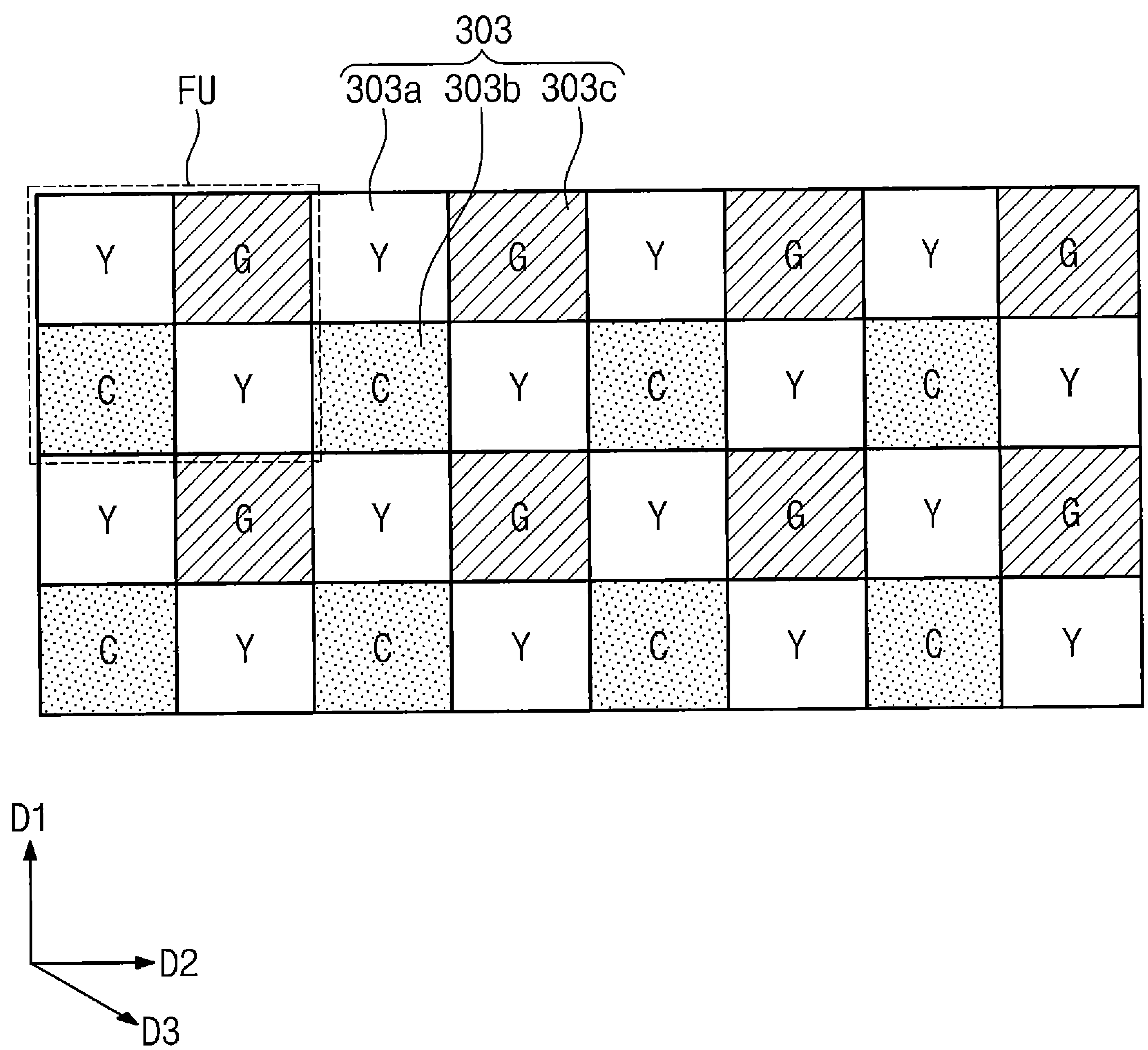


FIG. 8A

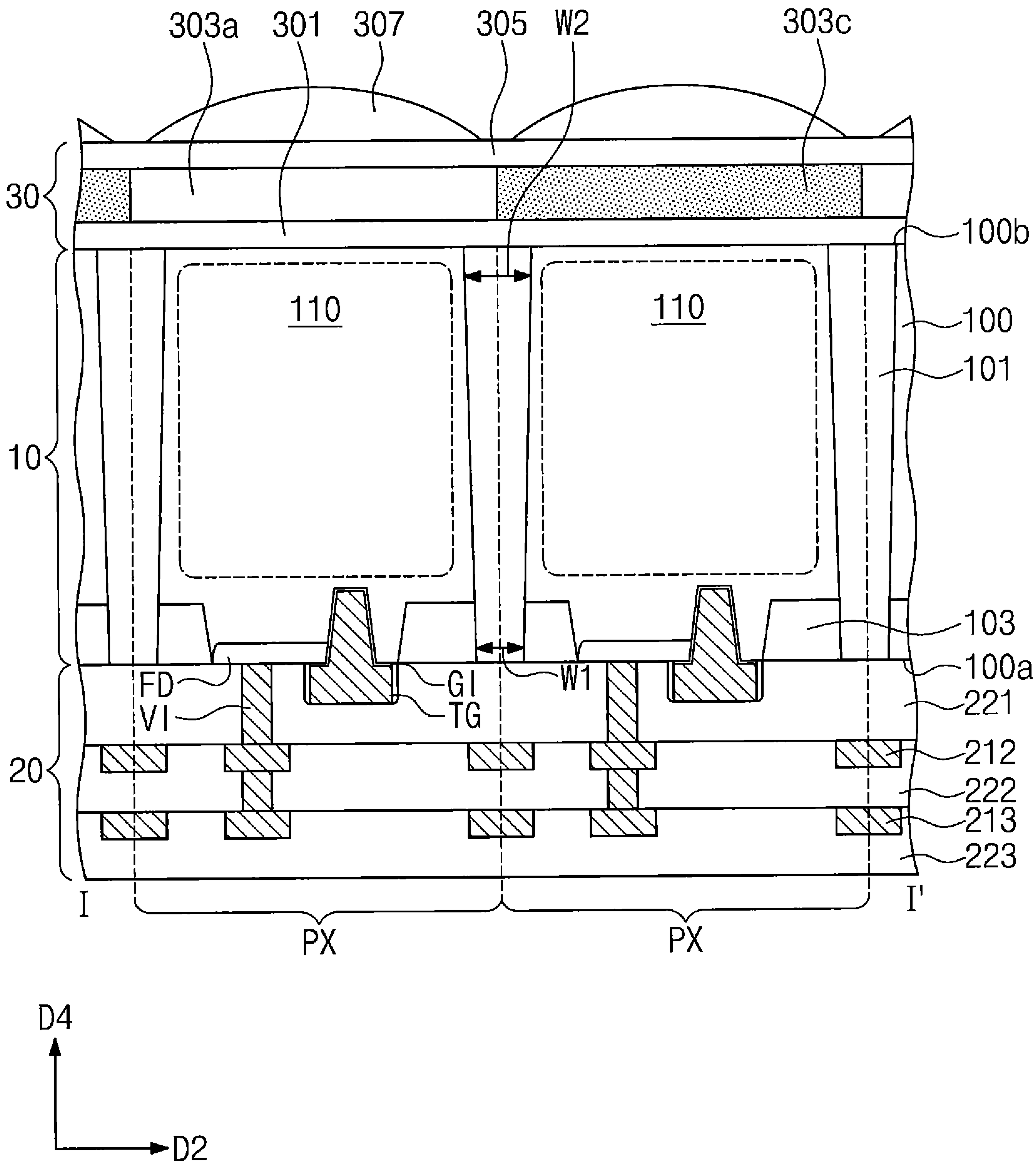
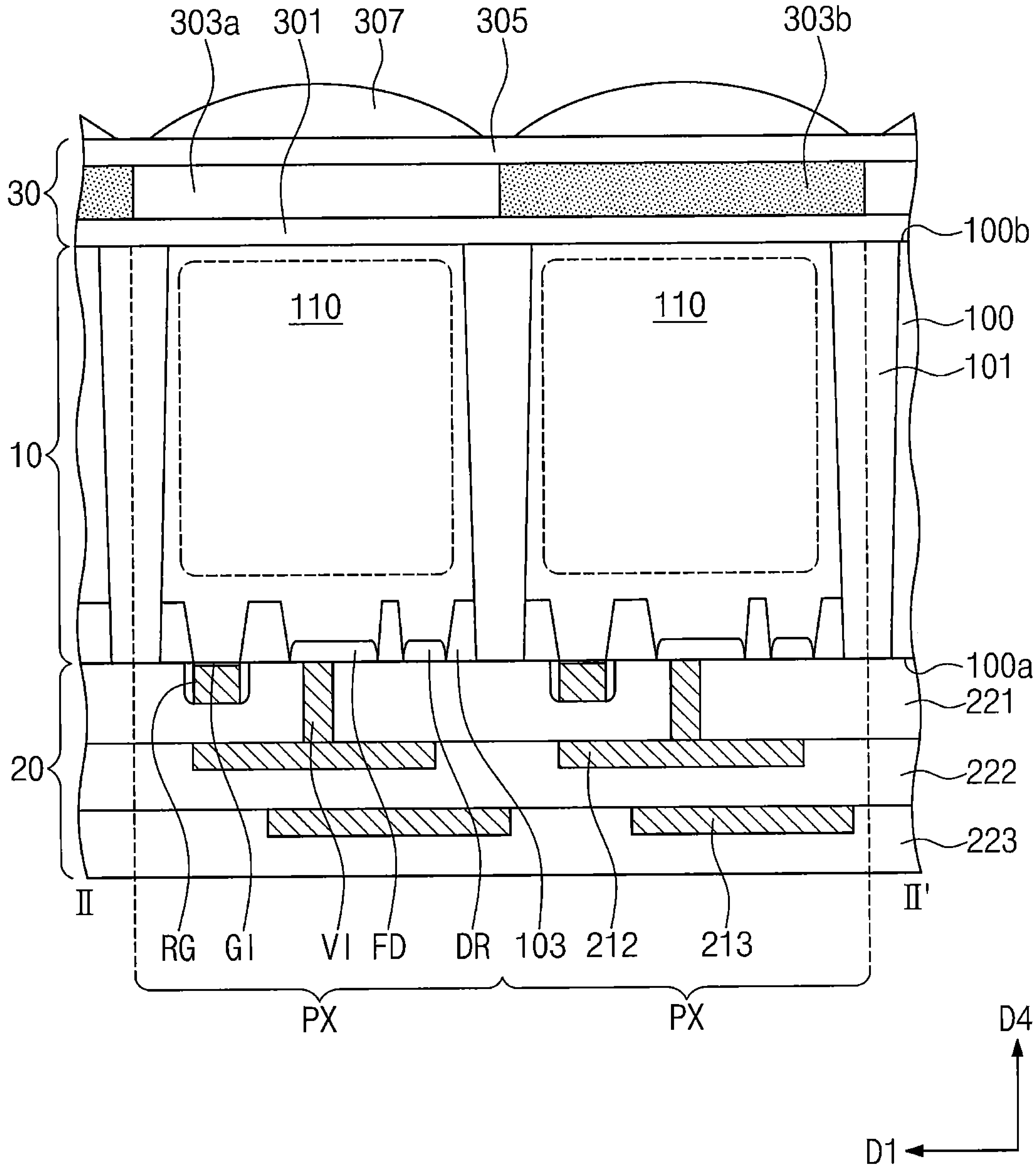

303a
301
307
305
W2
303c
30
100b
110
110
100
101
10
103
100a
FD
GI
W1
VI
TG
221
20
212
222
213
223
I
I'
PX
PX
D4
D2

FIG. 8B



303a
301
307
305
303b
30
100b
110
110
100
101
10
100a
221
20
222
223
II
II'
RG
GI
VI
FD
DR
103
212
213
PX
PX
D4
D1

FIG. 9A

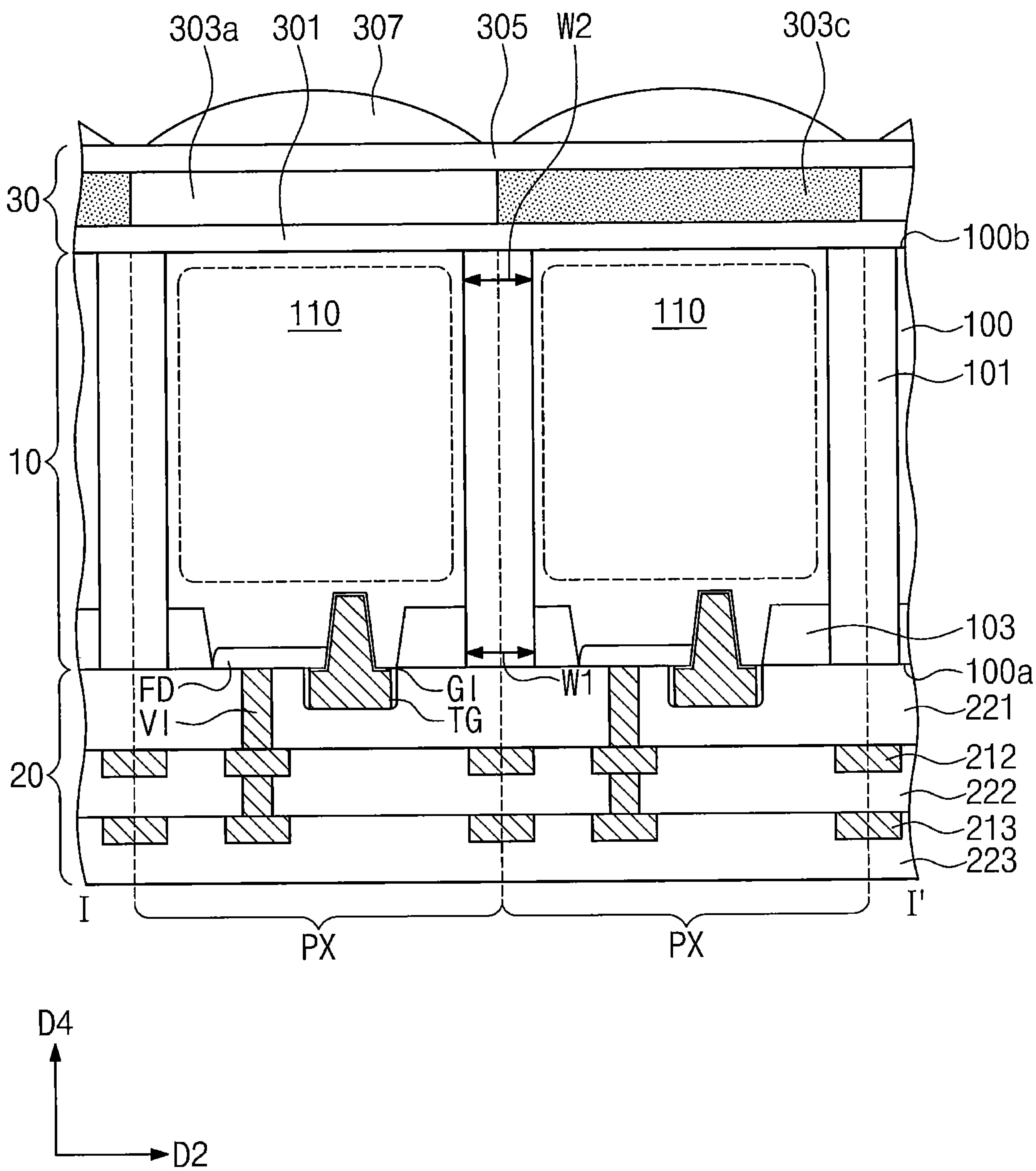

303a
301
307
305
W2
303c
30
100b
110
110
100
101
10
103
100a
FD
VI
GI
TG
W1
221
212
20
222
213
223
I
I'
PX
PX
D4
D2

FIG. 9B

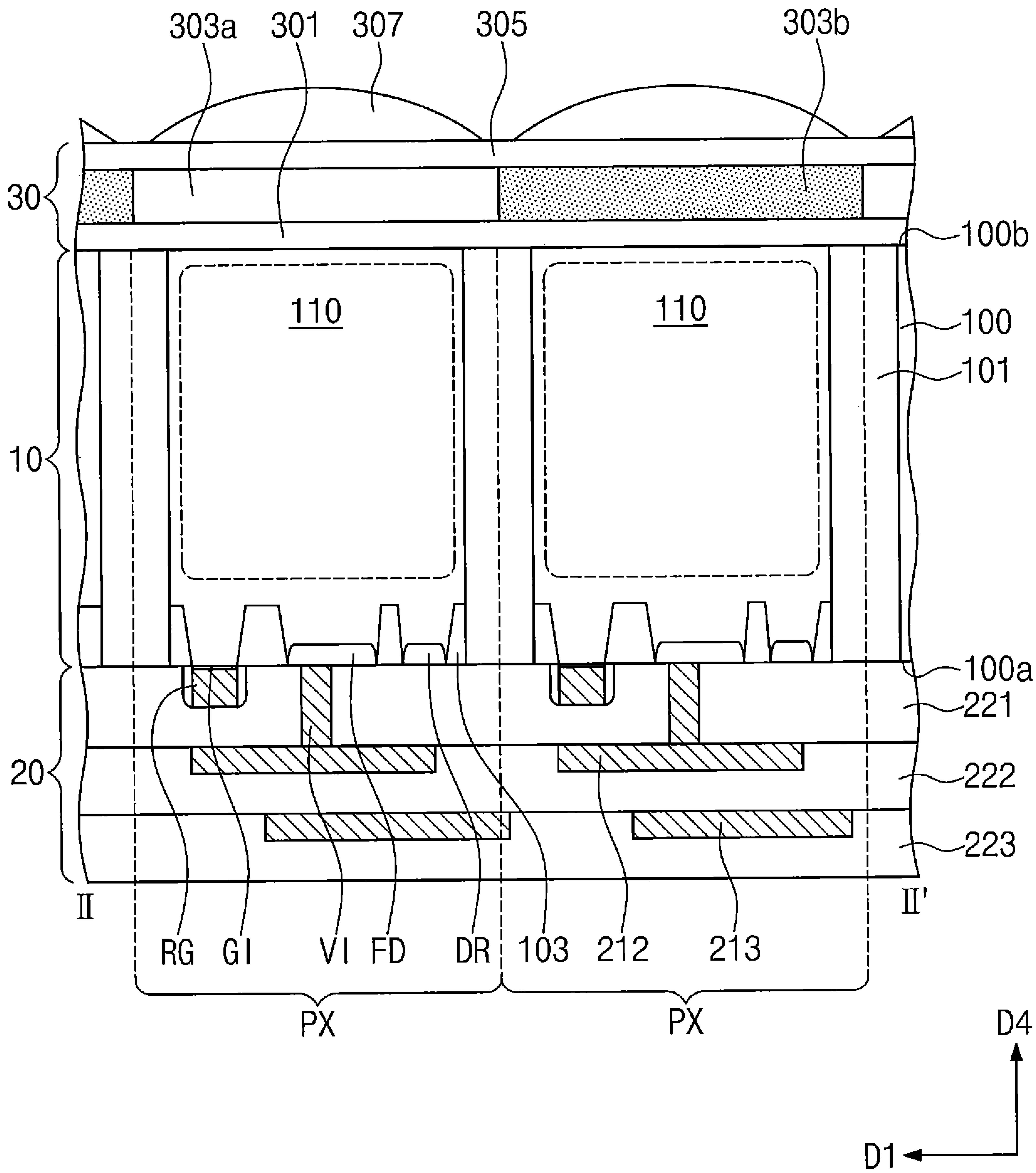
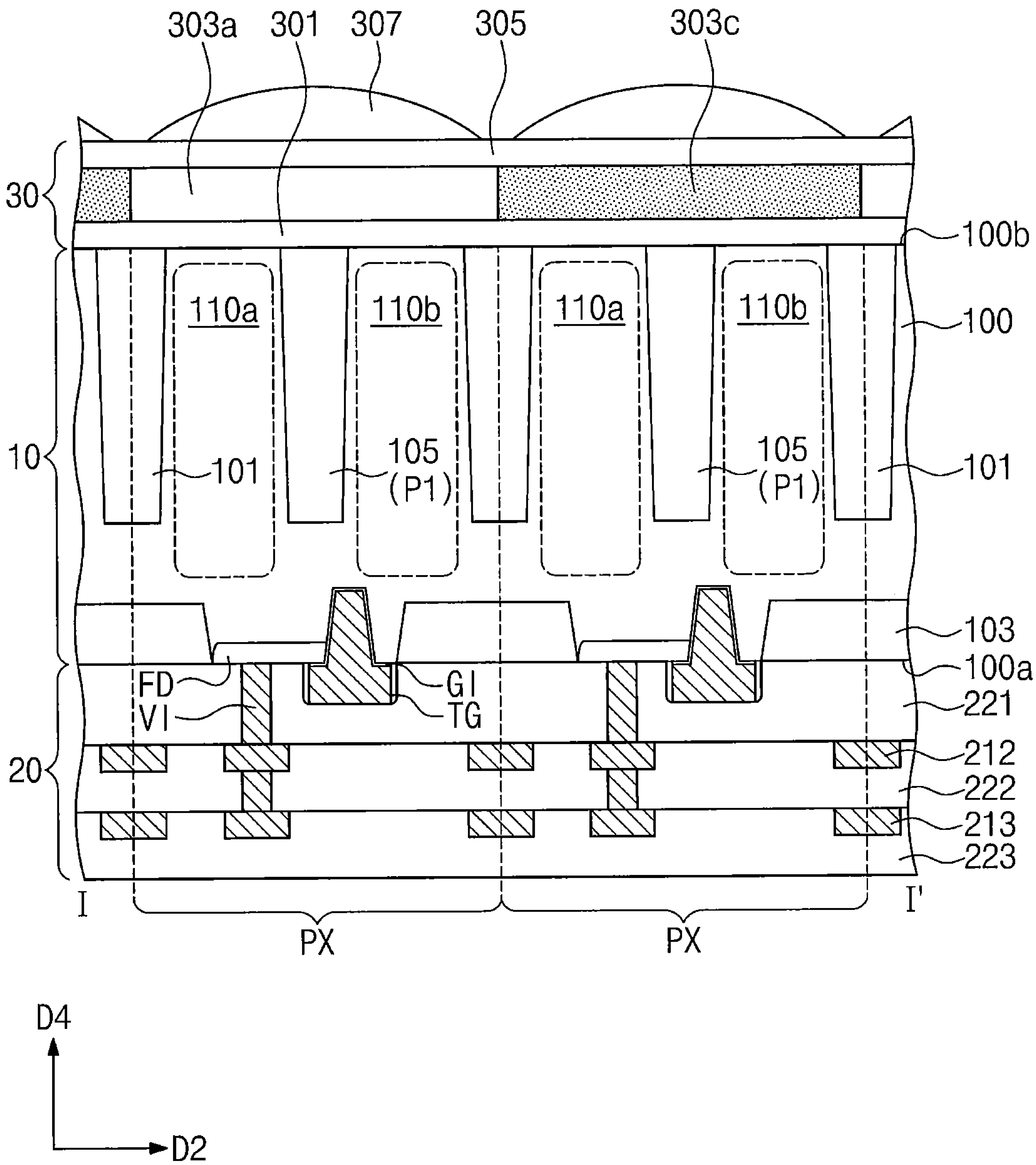
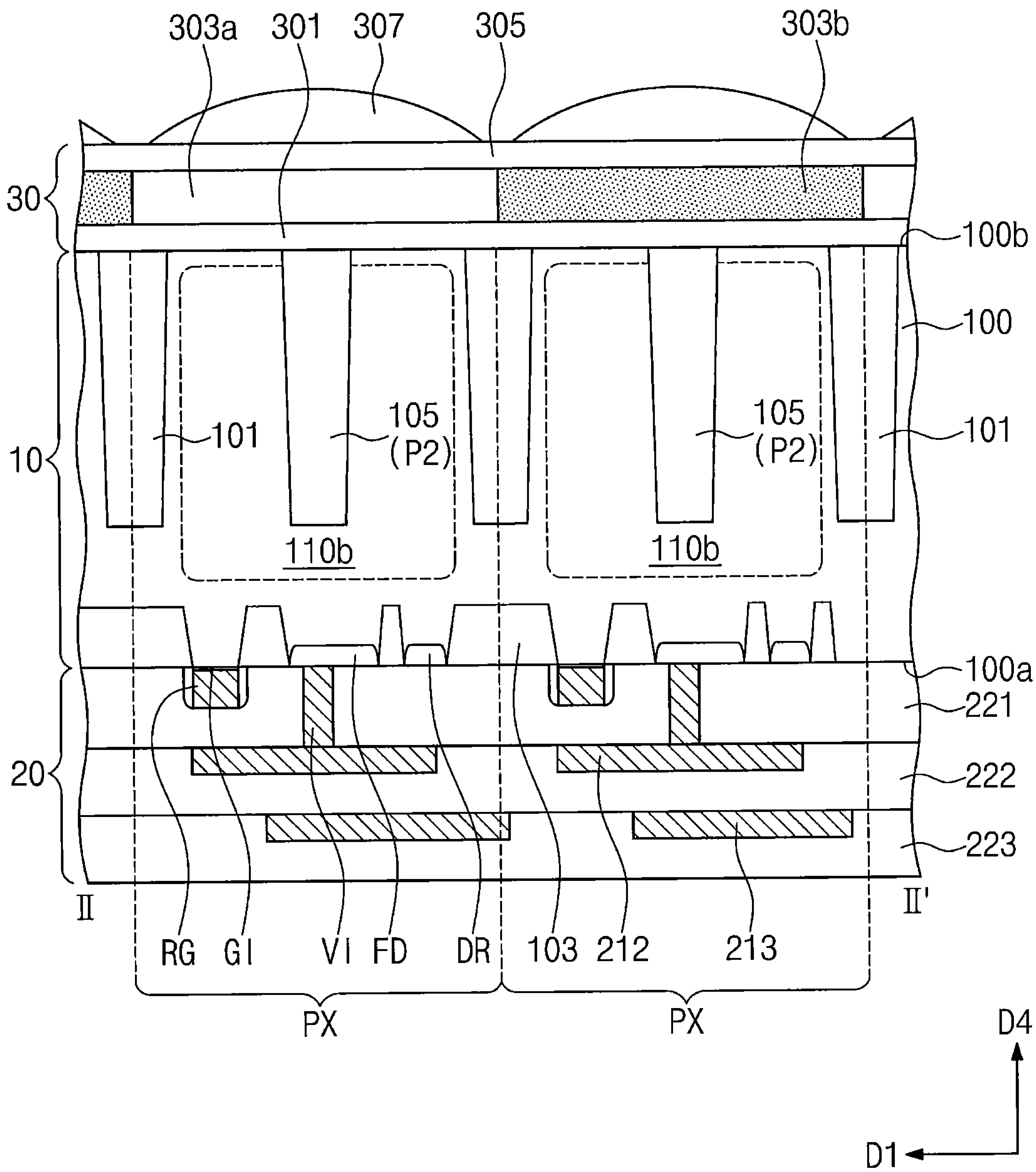

303a
301
307
305
303b
30
100b
110
110
100
101
10
100a
221
20
222
223
II
II'
RG
GI
VI
FD
DR
103
212
213
PX
PX
D4
D1

FIG. 10A



303a
301
307
305
303c
30
100b
110a
110b
110a
110b
100
10
101
105
(P1)
105
(P1)
101
103
100a
FD
GI
VI
TG
221
212
20
222
213
223
I
I'
PX
PX
D4
D2

FIG. 10B



303a
301
307
305
303b
30
100b
100
10
101
105
(P2)
105
(P2)
101
110b
110b
100a
221
20
222
223
II
II'
RG
GI
VI
FD
DR
103
212
213
PX
PX
D4
D1

IMAGE SENSORS

CROSS-REFERENCE TO RELATED APPLICATION

This U.S. non-provisional application claims priority under 35 U.S.C § 119 to Korean Patent Application No. 10-2018-0002920 filed on Jan. 9, 2018, in the Korean Intellectual Property Office, the disclosure of which is hereby incorporated by reference in its entirety.

BACKGROUND

The present disclosure generally relates to an image sensor, and more particularly, to a complementary metal oxide semiconductor (CMOS) image sensor.

Image sensors convert optical images into electrical signals. Recent advances in the computer and communication industries have led to strong demand for high performance image sensors in various consumer electronic devices such as digital cameras, camcorders, PCSs (Personal Communication Systems), game devices, security cameras, medical micro-cameras, etc.

Image sensors encompass various types, including a charge coupled device (CCD) type and a complementary metal oxide semiconductor (CMOS) type. Operation of CMOS image sensors may be less complicated, and sizes of CMOS image sensors may be possibly minimized since signal processing circuits could be integrated into a single chip. CMOS image sensors may consume relatively small amount of power and thus may be beneficial in view of battery capacity. In addition, since manufacturing processes of CMOS image sensors may be compatible with CMOS process technology, the CMOS image sensors may be manufactured with low cost.

SUMMARY

Embodiments of the inventive concept provide image sensors with improved optical characteristics.

According to example embodiments of inventive concept, image sensors may include a plurality of unit pixels and a color filter array on the plurality of unit pixels. The color filter array may include a color filter unit including four color filters that are arranged in a two-by-two array, and the color filter unit may include two yellow color filters, a cyan color filter, and one of a red color filter or a green color filter.

According to example embodiments of inventive concept, images sensor may include a color filter including two yellow color filters, a cyan color filter, and a red color filter that are in a two-by-two array:

$$\begin{bmatrix} Y & R \\ C & Y \end{bmatrix}$$

Y represents one of the two yellow color filters, C represents the cyan color filter, and R represents the red color filter.

According to example embodiments of inventive concept, image sensors may include a substrate including a plurality of photoelectric conversion devices and a color filter unit on the substrate. The color filter unit may include four color filters including two first color filters, a second color filter, and a third color filter that are in a two-by-two array:

$$\begin{bmatrix} \text{first color filter} & \text{third color filter} \\ \text{second color filter} & \text{first color filter} \end{bmatrix}$$

Each of the two first color filters and the second color filter may be a complementary color filter, and the third color filter may be a primary color filter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a block diagram of an image sensor according to example embodiments of the present inventive concept.

FIG. **2** illustrates a circuit diagram of an active pixel sensor array of an image sensor according to example embodiments of the present inventive concept.

FIG. **3** illustrates a plan view of a color filter array of an image sensor according to example embodiments of the present inventive concept.

FIGS. **4**A and **4**B illustrate cross-sectional views respectively taken along the lines I-I' and the II-II' of FIG. **3** according to example embodiments of the present inventive concept.

FIG. **5**A is a graph showing transmittance characteristics of a primary color filter array according to example embodiments of the present inventive concept.

FIG. **5**B is a graph showing transmittance characteristics of a complementary color filter array according to example embodiments of the present inventive concept.

FIG. **6** is a graph showing transmittance characteristics of a color filter array according to example embodiments of the present inventive concept.

FIG. **7** illustrates a plan view of a color filter array of an image sensor according to example embodiments of the present inventive concept.

FIGS. **8**A, **8**B, **9**A, **9**B, **10**A, and **10**B illustrate cross-sectional views of an image sensor according to example embodiments of the present inventive concept.

DETAILED DESCRIPTION

As used herein the term "and/or" includes any and all combinations of one or more of the associated listed items. It will be understood that like reference numerals refer to like parts throughout the various figures unless otherwise specified.

It will be understood that "formed concurrently" refers to being formed in a same fabrication step, at approximately (but not necessarily exactly) the same time.

FIG. **1** illustrates a block diagram of an image sensor according to example embodiments of the inventive concept.

Referring to FIG. **1**, an image sensor may include an active pixel sensor array (APS) **1**, a row decoder **2**, a row driver **3**, a column decoder **4**, a timing generator **5**, a correlated double sampler (CDS) **6**, an analog-to-digital converter (ADC) **7**, and an input/output (I/O) buffer **8**.

The active pixel sensor array **1** may include a plurality of two-dimensionally arranged unit pixels, each of which is configured to convert optical signals into electrical signals. The active pixel sensor array **1** may be driven by a plurality of driving signals such as, for example, a pixel select signal, a reset signal, and/or a charge transfer signal that the row driver **3** generate and/or provide. The correlated double sampler **6** may be provided with the converted electrical signals.

The row driver **3** may provide the active pixel sensor array **1** with driving signals for driving unit pixels in accordance with a decoded result obtained from the row decoder **2**. When the unit pixels are arranged in a matrix shape, the driving signals may be supplied to respective rows.

The timing generator **5** may provide the row decoder **2** and the column decoder **4** with timing and control signals.

The correlated double sampler **6** may receive the electrical signals generated in the active pixel sensor array **1** and may hold and/or sample the received electrical signals. The correlated double sampler **6** may perform a double sampling operation to sample a specific noise level and a signal level of the electrical signal and then may output a difference level corresponding to a difference between the noise and signal levels.

The analog-to-digital converter (ADC) **7** may convert analog signals, which correspond to the difference level output from the correlated double sampler **6**, into digital signals and then may output the converted digital signals.

The input/output buffer **8** may latch the digital signals and then may sequentially output the latched digital signals to an image signal processing unit (not shown) in response to the decoded result obtained from the column decoder **4**.

FIG. **2** illustrates a circuit diagram showing an active pixel sensor array of an image sensor according to example embodiments of the inventive concept.

Referring to FIGS. **1** and **2**, a sensor array **1** may include a plurality of unit pixels PX, which may be arranged in a matrix shape. Each of the unit pixels PX may include a transfer transistor TX and logic transistors RX, SX, and DX. The logic transistors may include a reset transistor RX, a select transistor SX, and a drive transistor DX. The transfer transistor TX may include a transfer gate TG. Each of the unit pixels PX may further include a photoelectric conversion device PD and a floating diffusion region FD.

The photoelectric conversion device PD may generate and accumulate photo-charges in proportion to an amount of externally incident light. The photoelectric conversion device PD may include, for example, a photodiode, phototransistor, a photogate, a pinned photodiode, or a combination thereof. The transfer transistor TX may transfer the charges generated in the photoelectric conversion device PD into the floating diffusion region FD. The floating diffusion region FD may accumulatively store the charges generated and transferred from the photoelectric conversion device PD. The drive transistor DX may be controlled by an amount of photo-charges accumulated in the floating diffusion region FD.

The reset transistor RX may periodically reset the charges accumulated in the floating diffusion region FD. The reset transistor RX may have a drain electrode connected to the floating diffusion region FD and a source electrode connected to a power voltage V_{DD}. When the reset transistor RX is turned on, the floating diffusion region FD may be supplied with the power voltage V_{DD} connected to the source electrode of the reset transistor RX. Accordingly, when the reset transistor RX is turned on, the charges accumulated in the floating diffusion region FD may be exhausted and thus the floating diffusion region FD may be reset. The reset transistor RX may include a reset gate RG.

The drive transistor DX may serve as a source follower buffer amplifier. The drive transistor DX may amplify a variation (e.g., change) in electrical potential of the floating diffusion region FD and output the amplified electrical potential to an output line V_{OUT}.

The select transistor SX may select each row of the unit pixels PX that are to be readout. When the select transistor SX is turned on, the power voltage V_{DD} may be applied to a drain electrode of the drive transistor DX. The select transistor SX may include a select gate SG.

FIG. **3** illustrates a plan view of a color filter array of an image sensor according to example embodiments of the inventive concept.

Referring to FIG. **3**, an active pixel sensor array **1** may include color filter units FU (i.e., a group of color filters). The color filter units FU may be two-dimensionally arranged both in a first direction D**1** (e.g., column direction) and in a second direction D**2** (e.g., a row direction). In some embodiments, each of the first direction D**1** and the second direction D**2** may be a horizontal direction, and the first direction D**1** may be perpendicular to the second direction D**2**. Each of the color filter units FU may include four color filters **303** that are arranged in a two-by-two (2×2) array (i.e., an array having two rows and two columns). In some embodiments, the four color filters **303** of a single color filter unit FU may be arranged to form a two-by-two (2×2) array, as illustrated in FIG. **3**. In some embodiments, each of the color filter units FU may include four color filters **303**. In some embodiments, each of the color filter units FU may consist of (i.e., may only include) four color filters **303**, as illustrated in FIG. **3**. The color filters **303** of the color filter units FU may be disposed to correspond to a plurality of unit pixels.

Each of the color filter units FU may include a first color filter **303***a*, a second color filter **303***b*, and a third color filter **303***c*. The first and second color filters **303***a* and **303***b* may be complementary color filters, and the third color filter **303***c* may be a primary color filter. For example, the first color filter **303***a* may be a yellow color filter, the second color filter **303***b* may be a cyan color filter, and the third color filter **303***c* may be a red color filter. Each of the color filter units FU may include two yellow color filters Y, cyan color filter C, and red color R filter that are arranged in a two-by-two (2×2) array below. In some embodiments, the two yellow color filters Y may be adjacent each other in a diagonal direction (i.e., the third direction D3) with respect to the first direction D**1** or the second direction D**2** as illustrated in FIG. **3**.

$$\begin{bmatrix} Y & R \\ C & Y \end{bmatrix}$$

The first color filter **303***a* may be configured to allow yellow visible light to pass through, and a unit pixel having the first color filter **303***a* may generate photo-charges corresponding to the yellow visible light. The second color filter **303***b* may be configured to allow cyan visible light to pass through, and a unit pixel having the second color filter **303***b* may generate photo-charges corresponding to the cyan visible light. The third color filter **303***c* may be configured to allow red visible light to pass through, and a unit pixel having the third color filter **303***c* may generate photo-charges corresponding to the red visible light.

In some embodiments, each of the first color filter **303***a*, the second color filter **303***b*, and the third color filter **303***c* overlaps a single corresponding one of photoelectric conversion regions **110**, as illustrated in FIGS. **4**A and **4**B. In other words, in some embodiments, the first color filter **303***a*, the second color filter **303***b*, and the third color filter **303***c* are in a one-to one relationship with the photoelectric conversion regions **110**, as illustrated in FIGS. **4**A and **4**B.

A single color filter unit FU may be provided with two first color filters **303***a*. For example, the first to third color filters **303**a, **303**b, and **303**c may be arranged in a Bayer pattern in which the number of first color filters **303**a is twice the number of second color filters **303**b or the number of third color filters **303**c.

In the active pixel sensor array **1**, the first color filters **303**a may be arranged in a third direction D**3**. The third direction D**3** may intersect both the first and second directions D**1** and D**2**. For example, the first color filters **303**a may be adjacent to each other neither in the first direction D**1** nor in the second direction D**2**. In the active pixel sensor array **1**, the second and third color filters **303**b and **303**c may be alternately arranged along the third direction D**3**. Each of the second and third color filters **303**b and **303**c may be disposed between neighboring first color filters **303**a.

In some embodiments, two first color filters **303**a of a single color filter unit FU may be arranged along the third direction D**3**, as illustrated in FIG. **3**. The third direction D**3** may be a horizontal direction and may form an angle with the first direction D**1** and the second direction D**2**.

FIGS. **4**A and **4**B illustrate cross-sectional views respectively taken along the lines I-I' and II-II' of FIG. **3** according to example embodiments of the inventive concept.

Referring to FIGS. **3**, **4**A, and **4**B, an image sensor according to some embodiments of the inventive concept may include a photoelectric conversion layer **10**, a wiring line layer **20**, and an optical transmittance layer **30**. The photoelectric conversion layer **10** may be interposed between the wiring line layer **20** and the optical transmittance layer **30**. The photoelectric conversion layer **10** may include a substrate **100** (e.g., semiconductor substrate) and photoelectric conversion regions **110** provided in the substrate **100**. The photoelectric conversion regions **110** may convert externally incident light into electrical signals. The photoelectric conversion regions **110** may generate electrical signals in response to incident light. It will be understood that the substrate **100** may include a semiconductor material. Accordingly, the substrate **100** is referred to as a semiconductor substrate **100** herein. However, it should be noted that a substrate **100** may include a non-semiconductor material.

The semiconductor substrate **100** may have a first surface **100**a (e.g., a front surface) and a second surface **100**b (e.g., a backside surface) opposite to each other. The wiring line layer **20** may be disposed on the first surface **100**a of the semiconductor substrate **100**, and the optical transmittance layer **30** may be disposed on the second surface **100**b of the semiconductor substrate **100**. In some embodiments, the first surface **100**a of the semiconductor substrate **100** may face the wiring line layer **20**, and the second surface **100**b of the semiconductor substrate **100** may face the optical transmittance layer **30**.

The wiring line layer **20** may include transfer transistors TX, logic transistors RX, SX, and DX, and first and second wiring lines **212** and **213**. The transfer transistors TX may be electrically connected to the photoelectric conversion regions **110**. The first and second wiring lines **212** and **213** may be connected, through vias VIs, to the transfer transistors TX and the logic transistors RX, SX, and DX. In some embodiments, a single through via VI may extend through a first interlayer dielectric layer **221**. The wiring line layer **20** may signally process the electrical signals converted in the photoelectric conversion regions **110**. The first and second wiring lines **212** and **213** may be disposed respectively in second and third interlayer dielectric layers **222** and **223** stacked on the first surface **100**a of the semiconductor substrate **100**. In some embodiments, the first and second wiring lines **212** and **213** may be arranged regardless of arrangement of the photoelectric conversion regions **110**.

For example, the first and second wiring lines **212** and **213** may cross over the photoelectric conversion regions **110**.

The optical transmittance layer **30** may include microlenses **307** and first to third color filters **303**a, **303**b, and **303**c. The optical transmittance layer **30** may focus and/or filter externally incident light, and the photoelectric conversion layer **10** may be provided with the focused and filtered light.

The semiconductor substrate **100** may be, for example, an epitaxial layer formed on a bulk silicon substrate having a first conductivity type (e.g., p-type) that is the same as a conductivity type of the epitaxial layer. The bulk silicon substrate may be removed from the semiconductor substrate **100** in the course of manufacturing an image sensor, and thus the semiconductor substrate **100** may include only the epitaxial layer of the first conductivity type. In some embodiments, the semiconductor substrate **100** may be a bulk semiconductor substrate including a well of the first conductivity type. In some embodiments, the semiconductor substrate **100** may include an epitaxial layer of a second conductivity type (e.g., n-type), a bulk silicon substrate of the second conductivity type, a silicon-on-insulator (SOI) substrate, or various substrate.

The semiconductor substrate **100** may include a plurality of unit pixels PX defined by a first device isolation layer **101**. The unit pixels PX may be two-dimensionally arranged both in a first direction D1 and in a second direction D**2** intersecting each other. For example, the unit pixels PX may be arranged in a matrix shape along the first and second directions D**1** and D**2**. When viewed in plan, in some embodiments, the first device isolation layer **101** may completely surround each of the unit pixels PX. The first device isolation layer **101** may reduce or possibly prevent photocharges generated from light incident onto each unit pixels PX from randomly drifting into neighboring unit pixels PX. The first device isolation layer **101** may accordingly inhibit or suppress cross-talk phenomenon between the unit pixels PX. In some embodiments, the first device isolation layer **101** may separate the plurality of unit pixels PX from each other. For example, the first device isolation layer **101** may separate and/or isolate (e.g., electrically isolate or physically isolate) the plurality of unit pixels PX from each other.

The first device isolation layer **101** may include an insulating material whose refractive index is less than that (e.g., silicon) of the semiconductor substrate **100**. The first device isolation layer **101** may include one or a plurality of insulation layers. For example, the first device isolation layer **101** may include a silicon oxide layer, a silicon oxynitride layer, or a silicon nitride layer.

When viewed in cross-section, the first device isolation layer **101** may extend from the first surface **100**a toward the second surface **100**b of the semiconductor substrate **100**. The first device isolation layer **101** may penetrate the semiconductor substrate **100**, while extending along a fourth direction D**4**. For example, the first device isolation layer **101** may have a depth substantially the same as a vertical thickness of the semiconductor substrate **100**. In some embodiments, the first device isolation layer **101** may extend completely through the semiconductor substrate **100**, as illustrated in FIGS. **4**A and **4**B. In some embodiments, as illustrated in FIGS. **4**A and **4**B, the first device isolation layer **101** may include opposing sides that are spaced apart from each other in a vertical direction (i.e., the fourth direction D**4**) and the opposing sides of the first device isolation layer **101** may be coplanar with the first surface **100**a and the second surface **100**b of the semiconductor substrate **100**, respectively.

The first device isolation layer **101** may have a width that decreases (e.g., gradually decreases) from the first surface **100***a* to the second surface **100***b* of the semiconductor substrate **100**. For example, the first device isolation layer **101** may have a first width W**1** in the second direction D**2** adjacent to the first surface **100***a* and a second width W**2** in the second direction D**2** adjacent to the second surface **100***b*, and the first width W**1** may be greater than the second width W**2**.

In some embodiments, the wiring line layer **20**, the photoelectric conversion layer **10**, and the optical transmittance layer **30** may be sequentially stacked in the fourth direction D**4**, as illustrated in FIG. **4**A. The fourth direction D**4** may be a vertical direction and may be perpendicular to the first, second and third D**1**, D**2**, and D**3** directions.

The photoelectric conversion regions **110** may be disposed in corresponding unit pixels PX. The photoelectric conversion regions **110** may be doped with impurities having the second conductivity type (e.g., n-type) opposite to a conductive type of the semiconductor substrate **100**. For example, the photoelectric conversion regions **110** may be adjacent to the second surface **100***b* of the semiconductor substrate **100** and vertically spaced apart from the first surface **100***a* of the semiconductor substrate **100**. Each of the photoelectric conversion regions **110** may include a first region adjacent to the first surface **100***a* and a second region adjacent to the second surface **100***b*, and the first region and the second region of the photoelectric conversion region **110** may have different impurity concentrations. Each of the photoelectric conversion regions **110** may thus have a potential slope between the first surface **100***a* and the second surface **100***b*.

The semiconductor substrate **100** and the photoelectric conversion regions **110** may constitute, for example, photodiodes. In each of the unit pixels PX, the photodiode may be constituted by a p-n junction between the semiconductor substrate **100** of the first conductivity type and the photoelectric conversion region **110** of the second conductivity type. Each of the photoelectric conversion regions **110** constituting the photodiodes may generate and/or accumulate photo-charges in proportion to magnitude of incident light.

The semiconductor substrate **100** may be provided therein with a second device isolation layer **103** that is adjacent to the first surface **100***a* and defines active patterns (i.e., active regions). Each of the unit pixels PX may include the active pattern. For example, the active pattern may include a floating diffusion region FD and an impurity region DR that are discussed below.

The second device isolation layer **103** may have a width that decreases (e.g., gradually decreases) from the first surface **100***a* toward the second surface **100***b* of the semiconductor substrate **100**. The second device isolation layer **103** may have a depth in the fourth direction D**4** less than a depth of the first device isolation layer **101** in the fourth direction D**4**. In some embodiments, the second device isolation layer **103** may have a thickness in the fourth direction D**4** less than a thickness of the first device isolation layer **101** in the fourth direction D**4**. The first device isolation layer **101** may vertically overlap a portion of the second device isolation layer **103**. The second device isolation layer **103** may include a silicon oxide layer, a silicon oxynitride layer, and/or a silicon nitride layer. For example, the first and second device isolation layers **101** and **103** may be integrally connected to each other.

Each of the unit pixels PX may be provided with a transfer transistor (e.g., TX of FIG. **2**). The transfer transistor may include a transfer gate TG and a floating diffusion region FD. The transfer gate TG may include a lower segment inserted into the semiconductor substrate **100** and may also include an upper segment that is connected to the lower segment and protrudes above the first surface **100***a* of the semiconductor substrate **100**. In some embodiments, as illustrated in FIG. **4**A, the transfer gate TG may include a portion in the semiconductor substrate **100** and a portion protruding from the semiconductor substrate **100**. A gate dielectric layer GI may be interposed between the transfer gate TG and the semiconductor substrate **100**. The floating diffusion region FD may have the second conductivity type (e.g., n-type) opposite to a conductivity type of the semiconductor substrate **100**.

Each of the unit pixels PX may be provided with a drive transistor (e.g., DX of FIG. **2**), a select transistor (e.g., SX of FIG. **2**), and a reset transistor (e.g., RX of FIG. **2**). The drive transistor may include a drive gate, the select transistor may include a select gate, and the reset transistor may include a reset gate. Impurity regions DR may be provided on an upper portion of the active pattern on opposite sides of each of the drive, select, and reset gates. For example, the impurity regions DR may have the second conductivity type (e.g., n-type) opposite to a conductive type of the semiconductor substrate **100**.

The second surface **100***b* of the semiconductor substrate **100** may be provided thereon with micro-lenses **307** and first to third color filters **303***a*, **303***b*, and **303***c*. Each of the first to third color filters **303***a*, **303***b*, and **303***c* may be disposed on a corresponding one of the unit pixels PX. Each of the micro-lenses **307** may be disposed on a corresponding one of the first to third color filters **303***a*, **303***b*, and **303***c*. A first planarization layer **301** may be disposed between the second surface **100***b* of the semiconductor substrate **100** and the first to third color filters **303***a*, **303***b*, and **303***c*, and a second planarization layer **305** may be disposed between the micro-lenses **307** and the first to third color filters **303***a*, **303***b*, and **303***c*.

The first and second color filters **303***a* and **303***b* may be complementary color filters, and the third color filter **303***c* may be a primary color filter. For example, the first color filter **303***a* may be a yellow color filter, the second color filter **303***b* may be a cyan color filter, and the third color filter **303***c* may be a red color filter.

Each of the micro-lenses **307** may have a convex shape to focus light that is incident onto the unit pixel PX. The micro-lenses **307** may vertically overlap corresponding photoelectric conversion regions **110**. In some embodiments, a single micro-lens **307** may overlap a single photoelectric conversion region **110**.

FIG. **5**A is a graph showing transmittance characteristics of a primary color filter array. Referring to FIG. **5**A, a primary color filter array may include a red color filter RCF, a green color filter GCF, and a blue color filter BCF. The blue color filter BCF may be transparent to blue light whose wavelength is about 450 nm. The green color filter GCF may be transparent to green light whose wavelength is about 530 nm. The red color filter RCF may be transparent to red light whose wavelength is about 600 nm. The primary color filter array may be transparent to three primary colors of red, green, and blue, thereby achieving relatively excellent sharpness. In contrast, the primary color filter array may decrease pixel sensitivity.

FIG. **5**B is a graph showing transmittance characteristics of a complementary color filter array. Referring to FIG. **5**B, a complementary color filter array may include a cyan color filter CCF, a magenta color filter MCF, and a yellow color filter YCF. Cyan, magenta, and yellow colors may respectively have a complementary relationship with red, green, and blue colors, i.e., the three primary colors. The cyan color filter CCF may be transparent to cyan light whose wavelength falls within a range from about 400 nm to about 550 nm. The yellow color filter YCF may be transparent to yellow light whose wavelength falls within a range from about 500 nm to about 650 nm. The magenta color filter MCF may be transparent to magenta light whose wavelength falls within a range from about 450 nm to about 600 nm. The magenta color filter MCF may be opaque to green light whose wavelength is about 530 nm.

The complementary color filter of FIG. **5**B may transmit light whose wavelength range is wider than that of light passing through the primary color filter array of FIG. **5**A. The complementary color filter array may accordingly have pixel sensitivity superior to that of the primary color filter array. In contrast, the complementary color filter array may have sharpness less than that of the primary color filter array.

FIG. **6** is a graph showing transmittance characteristics of a color filter array according to example embodiments of the inventive concept. Referring to FIG. **6**, a color filter array according to example embodiments of the inventive concept may include two complementary color filters (e.g., cyan and yellow colors) and one primary color filter (e.g., red color). The color filter array of the inventive concept may transmit light whose wavelength range is wider than that of light passing through the primary color filter array of FIG. **5**A. The color filter array according to example embodiments of the inventive concept may accordingly have pixel sensitivity superior to that of the primary color filter array. The color filter array of the inventive concept may exactly transmit red light, compared to the complementary color filter array of FIG. **5**B. The color filter array of the inventive concept may therefore have sharpness greater than that of the complementary color filter array.

FIG. **7** illustrates a plan view of a color filter array of an image sensor according to example embodiments of the inventive concept. A detailed description of technical features repetitive to those discussed above with reference to FIG. **3** may be omitted, and differences will be discussed in detail. Referring to FIG. **7**, each of the color filter units FU may include two first color filters **303***a*, a second color filter **303***b*, and a third color filter **303***c*. The third color filter **303***c* may be a green color filter.

FIGS. **8**A, **8**B, **9**A, **9**B, **10**A, and **10**B illustrate cross-sectional views of an image sensor according to example embodiments of the inventive concept. FIGS. **8**A, **9**A, and **10**A illustrate cross-sectional views taken along the line I-I' of FIG. **3**, and FIGS. **8**B, **9**B, and **10**B illustrate cross-sectional views taken along the line II-II' of FIG. **3**. A detailed description of technical features repetitive to those discussed above with reference to FIGS. **3**, **4**A, and **4**B may be omitted, and differences will be discussed in detail.

Referring to FIGS. **3**, **8**A, and **8**B, the first device isolation layer **101** may have a width that gradually increase from the first surface **100***a* toward the second surface **100***b*. The first device isolation layer **101** may have a first width W**1** adjacent to the first surface **100***a* and a second width W**2** adjacent to the second surface **100***b*, and the second width W**2** may be greater than the first width W**1**.

Referring to FIGS. **3**, **9**A, and **9**B, the first device isolation layer **101** may have a constant width regardless of a depth of the first device isolation layer **101**. In some embodiments, the first device isolation layer **101** may have a uniform width in a horizontal direction (e.g., the second direction D**2**) along a vertical direction (e.g., the fourth direction D**4**), as illustrated in FIG. **9**A. The first device isolation layer **101** may have a first width W**1** adjacent to the first surface **100***a* and a second width W**2** adjacent to the second surface **100***b*, and the first and second widths W**1** and W**2** may be substantially the same as each other. For example, a difference between the first and second widths W**1** and W**2** may be less than 3%, 5%, 10% or 15% of the first and second widths W**1** and W**2**.

Referring to FIGS. **3**, **10**A, and **10**B, the photoelectric conversion layer **10** may include a semiconductor substrate **100** and first and second photoelectric conversion regions **110***a* and **110***b* that are provided in the semiconductor substrate **100**. The first and second photoelectric conversion regions **110***a* and **110***b* may convert externally incident light into electrical signals. A pair of first and second photoelectric conversion regions **110***a* and **110***b* may be provided in each of the unit pixels PX. Each of the first and second photoelectric conversion regions **110***a* and **110***b* may be doped with impurities having the second conductivity type (e.g., n-type) opposite to a conductivity type of the semiconductor substrate **100**.

Each of the first and second photoelectric conversion regions **110***a* and **110***b* may include a first region adjacent to the first surface **100***a* and a second region adjacent to the second surface **100***b*, and the first and second regions have different impurity concentrations. Each of the first and second photoelectric conversion regions **110***a* and **110***b* may then have a potential slope between the first and second surfaces **100***a* and **100***b* of the semiconductor substrate **100**.

The semiconductor substrate **100** and the first and second photoelectric conversion regions **110***a* and **110***b* may constitute a pair of photo diodes. In each of the unit pixels PX, the pair of photodiodes may be constituted by p-n junctions between the semiconductor substrate **100** of the first conductivity and the first conversion region **110***a* and between the semiconductor substrate **100** of the first conductivity and the second photoelectric conversion region **110***b* of the second conductivity.

In each of the unit pixels PX, a difference in phase (e.g., phase offset or phase difference) may be provided between an electrical signal output from the first photoelectric conversion region **110***a* and an electrical signal output from the second photoelectric conversion region **110***b*. In an image sensor illustrated in FIGS. **10**A and **10**B, correction in focus may be performed by comparing the difference in phase between the electrical signals output from a pair of the first and second photoelectric conversion regions **110***a* and **110***b*.

In each of the unit pixels PX, a third device isolation layer **105** may be disposed between the first and second photoelectric conversion regions **110***a* and **110***b*. When viewed in plan, the third device isolation layer **105** may include a first part P**1** extending in the first direction D**1** while running across one unit pixel PX and a second part P**2** extending in the second direction D**2** while running across the one unit pixel PX. For example, the third device isolation layer **105** may have a cross shape in a plan view. The first part P**1** of the third device isolation layer **105** may be disposed between the first and second photoelectric conversion regions **110***a* and **110***b*. The second part P**2** of the third device isolation layer **105** may run across the first and second photoelectric conversion regions **110***a* and **110***b*. The third device isolation layer **105** may extend from the second surface **100***b* toward the first surface **100***a* of the semiconductor substrate **100**. The third device isolation layers **105** may be spaced apart from the first surface **100***a* of the semiconductor substrate **100**. In some embodiments, the third device isolation layers **105** may not extend through the semiconductor substrate **100** and thus may be vertically spaced apart from the first surface **100***a* of the semiconductor substrate **100** as illustrated in FIGS. **10**A and **10**B.

In some embodiments, the first device isolation layer **101** and the third device isolation layer **105** may be formed at the same time (e.g., concurrently). In some embodiments, the third device isolation layer **105** may include the same insulating material as that of the first device isolation layer **101**. The third device isolation layer **105** may be integrally connected to the first device isolation layer **101**. In some embodiments, the third device isolation layer **105** and the first device isolation layer **101** may have a unitary structure, and an interface between the third device isolation layer **105** and the first device isolation layer **101** may not be visible.

The third device isolation layer **105** may reduce or possibly prevent cross-talk between the first and second photoelectric conversion regions **110***a* and **110***b* in each of the unit pixels PX. Accordingly, each of the unit pixels PX may be configured to detect (e.g., exactly detect) a phase difference of an electrical signal. As a result, an image sensor according to some embodiments of the inventive concept may have an increased auto-focusing function.

According to inventive concept, an image sensor may have pixel sensitivity superior to that of a primary color filter array including (e.g., consisting of) red, green, and blue colors. Also, the image sensor may have sharpness (e.g., image sharpness) superior to that of a complementary color filter array including (e.g., consisting of) cyan, magenta, and yellow colors.

Although example embodiments of the inventive concept have been discussed with reference to accompanying figures, it will be understood that various changes in form and details may be made therein without departing from the spirit and scope of the inventive concept. It therefore will be understood that the embodiments described above are just illustrative, not restrictive, and the appended claims are intended to cover all such modifications, enhancements, and other embodiments, which fall within the true spirit and scope of the inventive concept. Thus, to the maximum extent allowed by law, the scope is to be determined by the broadest permissible interpretation of the following claims and their equivalents, and shall not be restricted or limited by the foregoing detailed description.

What is claimed is:

1. An image sensor comprising:

a plurality of unit pixels; and

a color filter array on the plurality of unit pixels,

wherein the color filter array comprises a color filter unit comprising four color filters that are arranged in a two-by-two array, and

wherein the color filter unit comprises two yellow color filters, a cyan color filter, and a red color filter.

2. The image sensor of claim **1**, wherein a first row of the two-by-two array of the color filter unit comprises the cyan color filter and a first one of the two yellow color filters, and

wherein a second row of the two-by-two array of the color filter unit comprises a second one of the two yellow color filters that is adjacent to the first one of the two yellow color filters in a diagonal direction with respect to a row direction.

3. The image sensor of claim **1**, wherein the color filter unit comprises a plurality of color filter units that comprises a plurality of yellow color filters, a plurality of cyan color filters, and a plurality of red color filters, and

wherein the plurality of yellow color filters, the plurality of cyan color filters, and the plurality of red color filters of the plurality of color filter units are in a Bayer pattern.

4. The image sensor of claim **1** further comprising a substrate comprising a first surface and a second surface opposite the first surface,

wherein each of the plurality of unit pixels comprises a photoelectric conversion region in the substrate, and

wherein the first surface of the substrate faces the color filter array.

5. The image sensor of claim **4**, wherein the substrate has a first conductivity type, and

wherein the photoelectric conversion region of each of the plurality of unit pixels has a second conductivity type different from the first conductivity type.

6. The image sensor of claim **4**, wherein each of the plurality of unit pixels further comprises a plurality of transistors on the second surface of the substrate.

7. The image sensor of claim **4** further comprising a device isolation layer in the substrate, wherein the device isolation layer isolates the plurality of unit pixels from each other.

8. The image sensor of claim **7**, wherein the first surface and the second surface of the substrate are spaced apart from each other in a vertical direction, and

wherein the device isolation layer has a first width in a horizontal direction adjacent to the first surface of the substrate and has a second width in the horizontal direction adjacent to the second surface of the substrate, and the first width is different from the second width.

9. An image sensor comprising:

a color filter unit comprising two yellow color filters, a cyan color filter, and a red color filter that are in a two-by-two array:

$$\begin{bmatrix} Y & R \\ C & Y \end{bmatrix}$$

wherein Y represents one of the two yellow color filters, C represents the cyan color filter, and R represents the red color filter.

10. The image sensor of claim **9**, wherein the color filter unit comprises a plurality of color filter units that are arranged two-dimensionally.

11. The image sensor of claim **9**, wherein the color filter unit comprises a plurality of color filter units that comprise a plurality of yellow color filters, a plurality of cyan color filters, and a plurality of red color filters, and

wherein the plurality of yellow color filters, the plurality of cyan color filters, and the plurality of red color filters of the plurality of color filter units are in a Bayer pattern.

12. The image sensor of claim **9**, further comprising a plurality of unit pixels arranged in a two-by-two array,

wherein each of the plurality of unit pixels is in one-to-one relationship with one of the yellow color filters, the cyan color filter, or the red color filter of the color filter unit,

wherein each of the plurality of unit pixels comprises:

a photoelectric conversion device;

a transfer transistor configured to control transfer of charges generated in the photoelectric conversion device; and

a floating diffusion region configured to receive the charges.

13. The image sensor of claim **12**, further comprising a substrate, wherein the photoelectric conversion device comprises a photoelectric conversion region in the substrate,

wherein the substrate has a first conductivity type, and

wherein the photoelectric conversion region has a second conductivity type that is different from the first conductivity type.

14. An image sensor comprising:

a substrate including a plurality of photoelectric conversion devices; and

a color filter unit on the substrate,

wherein the color filter unit comprises four color filters that comprise two first color filters, a second color filter, and a third color filter that are in a two-by-two array:

$$\begin{bmatrix} \text{first color filter} & \text{third color filter} \\ \text{second color filter} & \text{first color filter} \end{bmatrix},$$

wherein each of the two first color filters and the second color filter is a complementary color filter, and

wherein the third color filter is a primary color filter that is a red color filter.

15. The image sensor of claim **14**, wherein colors of the second and third color filters have a complementary relationship with each other.

16. The image sensor of claim **14**, wherein each of the two first color filters is a yellow color filter, and the second color filter is a cyan color filter.

17. The image sensor of claim **14**, wherein the color filter unit comprises a plurality of color filter units, and

wherein the first, second and third color filters of the plurality of color filter units are in a Bayer pattern.

18. The image sensor of claim **14**, wherein each of the first, second and third color filters overlaps a respective one of the plurality of photoelectric conversion devices.

19. The image sensor of claim **14**, wherein each of the first, second and third color filters overlaps a pair of the plurality of photoelectric conversion devices.

20. The image sensor of claim **14**, wherein each of the plurality of photoelectric conversion devices comprises a photoelectric conversion region in the substrate,

wherein the substrate has a first conductivity type, and

wherein the photoelectric conversion region has a second conductivity type that is different from the first conductivity type.

* * * * *